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Combustion Modification Controls for Residential and Commercial Heating Systems. Volume II: Oil-Fired Residential Furnace Field Test

(U.S.) Acurex Corp.
Mountain View, CA

Prepared for

Industrial Environmental Research Lab.
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COMBUSTION MODIFICATION CONTROLS FOR RESIDENTIAL AND COMMERCIAL HEATING SYSTEMS

Volume II. Oil-fired Residential Furnace Field Test

Prepared for

Office of Air Quality Planning and Standards

Prepared by

Industrial Environmental Research
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16. ABSTRACT The report gives methods and results of an environmental assessment test program at an oil-fired, low-emission residential heating unit. The aim of the program was to measure emissions changes resulting from changing the operating mode of the low-emission furnace. Emissions of trace elements, organic materials, sulfur species, NO, CO, hydrocarbons, and particulate matter were measured. Both continuous and cyclic operating modes were evaluated. Test results showed that organic material and CO emissions were greater in the cyclic operation test. NO emissions were slightly higher in the continuous operation test. Particulate and trace element emissions remained unchanged, and the sulfur species tests were inconclusive.

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COMBUSTION MODIFICATION CONTROLS FOR RESIDENTIAL AND COMMERCIAL HEATING SYSTEMS VOLUME II: OIL-FIRED RESIDENTIAL FURNACE FIELD TEST

by

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ABSTRACT

This test report describes the methods and results of an environmental assessment test program conducted on an oil-fired low emission residential heating unit. The purpose of the test program was to measure changes in emissions that result from changing the operating characteristics of this low emission furnace. Emissions of trace elements, organic materials, sulfur species, NO, CO, hydrocarbons, and particulate matter, were measured. Both continuous and cyclic operating modes were evaluated.

The results of the test show that organic material and CO emissions were greater in the cyclical operation test. NO emissions were slightly higher in the continuous operation test. Particulate and trace element emissions remained unchanged and the sulfur species tests were inconclusive.

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SECTION 1

INTRODUCTION

This report is part of a series of test reports resulting from the experimental testing task of the "Environmental Assessment of Stationary Source NO_x Control Technologies" (NO_x EA), Environmental Protection Agency (EPA) contract 68-02-2160. The NO_x EA is a 3-year program to: (1) identify the multimedia environmental impact of stationary combustion sources and combustion modification NO_x controls; and (2) identify the most cost-effective environmentally-sound NO_x controls for attaining and maintaining projected and current NO_2 air quality standards to the year 2000.

During the first year of the NO_x EA, a preliminary environmental assessment concluded that emissions and operating data needed to perform adequate process engineering and environmental assessment activities were severely lacking in several key areas. Most noteworthy was the virtual absence of data on noncriteria flue gas emissions and liquid and solid effluents (Reference 1). In response to these identified data needs, NO_x EA field test programs were initiated. Source selection was based on a source/control priority listing developed in the preliminary environmental assessment. These test programs were designed to provide information on changes in emissions and operation due to NO_x controls. The NO_x EA field test program is outlined in Table 1-1.

TABLE 1-1. NO_x EA FIELD TEST PROGRAM

Source Category	Description	Test Points (Unit Operation)	Sampling Protocol	Test Collaborator	Status
Coal-fired Utility Boiler	Kingston #6; 180 MW tangential; twin furnace, 12 burners/ furnace, 3 elevations; cyclone, 2 ESP's for particulate control	Baseline Biased Firing (2) BOOS (2)	Continuous NO_x, SO_2, CO CO_2, O_2 Inlet to 1st ESP: -- SASS -- Method 5 -- Method 8 -- Gas grab (C_1-C_6 HC) Outlet of 1st ESP: -- SASS -- Method 5 -- Method 8 -- Gas grab (C_1-C_6 HC) Bottom ash Hopper ash (1st ESP, cyclone) Fuel Operating data	TVA	Complete August 1977
Coal-fired Utility Boiler	Crist #7, 500 MW opposed wall fired; 24 burners, 3 elevations; ESP for particulate control	Baseline BOOS (2)	Continuous NO_x, CO, CO_2 O_2 ESP inlet -- SASS -- Method 5 -- Method 8 -- Gas grab (C_1-C_6 HC) ESP outlet -- SASS -- Method 5 -- Method 8 -- Gas grab (C_1-C_6 HC) Bottom ash ESP hopper ash Fuel Operating data Bioassay	Exxon	Complete June 1978

TABLE 1-1. Continued

Source Category	Description	Test Points (Unit Operation)	Sampling Protocol	Test Collaborator	Status
Oil-fired Utility Boiler	Moss Landing #6; 740 MW opposed wall fired; 48 burners, 6 elevations	Baseline FGR FGR + OFA	Continuous NO_x, CO, CO_2 O_2 SAS Method 5 Method 8 Gas grab (C_1-C_6 HC) Fuel Operating data Bioassay	New test start	Complete September 1978
Coal-fired Industrial	Traveling grate spreader stoker, 38 kg/s (300,000 lb/hr), ESP for particulate control; wet scrubber for SO_x control	Baseline LEA + High OFA	Continuous NO_x, CO, CO_2 O_2 Boiler exit: -- SASS -- Method 5 -- Shell-Emeryville -- Gas grab (C_1-C_6 HC) ESP outlet -- SASS -- Method 5 -- Shell-Emeryville -- Gas grab (C_1-C_6 HC) Bottom ash Cyclone hopper ash Fuel Operating data	KVB	Complete October 1977
Coal-fired Industrial	Traveling grate spreader stoker, 25 kg/s (200,000 lb/hr), ESP for particulate control;	Baseline LEA + High OFA	Continuous NO_x, SO_2, CO CO_2, O_2 Boiler exit: -- SASS -- Method 5 -- Shell-Emeryville -- Gas grab (C_1-C_6 HC) ESP outlet -- SASS -- Method 5 -- Shell-Emeryville -- Gas grab (C_1-C_6 HC) Bottom ash ESP hopper ash Fuel Operating data Bioassay	KVB	Complete February 1978

TABLE 1-1. Concluded

Source Category	Description	Test Points (Unit Operation)	Sampling Protocol	Test Collaborator	Status
Oil-fired Gas Turbine	T.H. Wharton Station, 60 MW GE MS 7001 C machine	Baseline Maximum water injection	Continuous NO_x, CO, CO_2 O_2 SASS Method 5 Method 8 Fuel Water Operating data Bioassay	General Electric	Complete, April 1978
Oil-fired Residential Heating Unit	Blueray low NO_x furnace, Medford, New York	Continuous Cycling	Continuous NO_x, CO, CO_2 O_2 SASS Method 5 Method 8 Fuel	New test start with EPA-RTP	Complete, November 1978

The test program documented in this report was conducted on a distillate oil-fired residential heating unit manufactured by Blueray Systems, Inc. Tests under continuous and cyclical operation were conducted. A description of this unit, the test plan, and test program results are discussed in the following sections.

SECTION 2

TEST SITE DESCRIPTION

The unit tested was a distillate oil-fired residential heating unit manufactured by Blueray Systems, Inc. This unit was installed in a Medford, Long Island, New York residence and had been in service for about one year.

The Blueray furnace is a low emission design that utilizes combustion gas recirculation to vaporize the oil and provide thorough mixing of the oil and air. The result is a low emission burner that is characterized by its diffuse blue flame that fills the combustion chamber. Most oil-fired units are characterized by a concentrated orange-yellow flame and consequently higher smoke and soot emissions.

The model tested was Blueray's BF-60. This unit fires distillate fuel oil at 0.63 mℓ/s (0.6 gal/hr). The rated heat input is 24.6 kJ/s (84,000 Btu/hr). The rated heat output is 20.5 kJ/s (70,000 Btu/hr). The rated heater efficiency is then 83.3 percent. Diagrams of the Blueray furnace and burner assembly are shown in Figures 2-1 and 2-2.

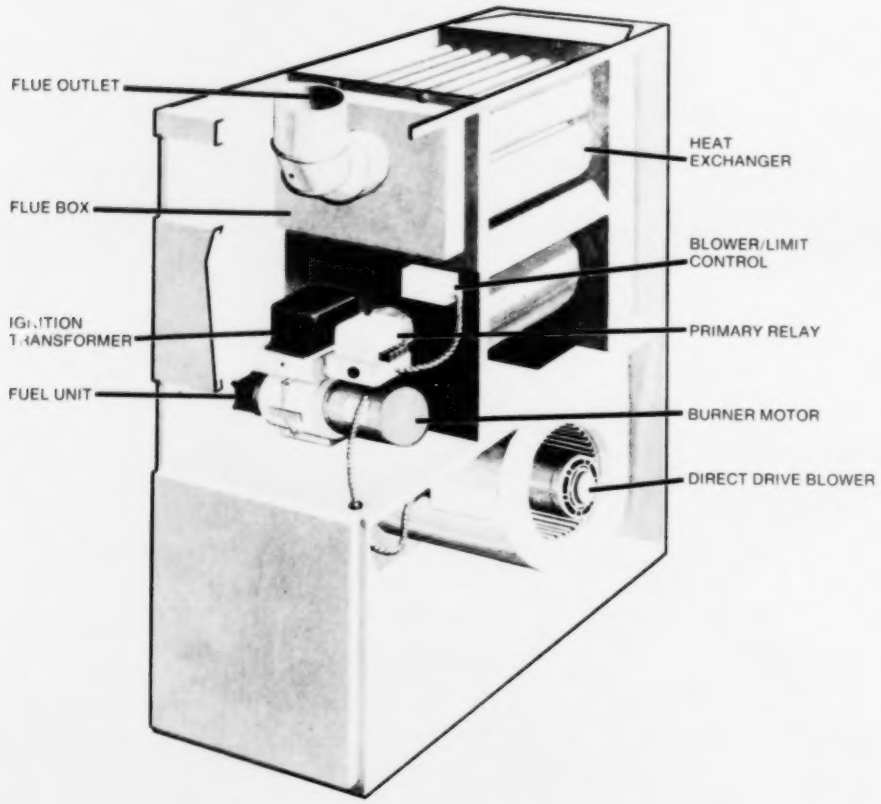

Figure 2-1. Blueray furnace diagram. (Reference 2)

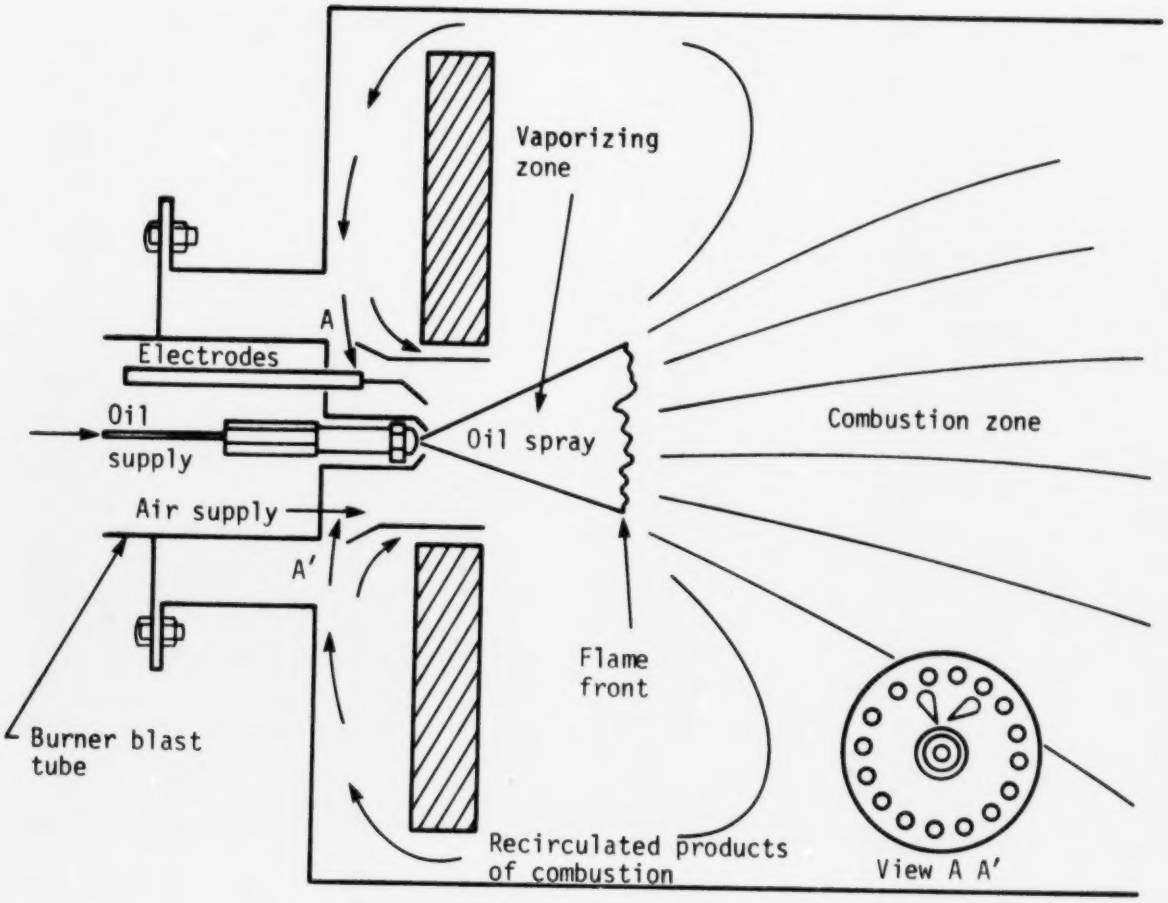

Figure 2-2. Blueray burner assembly diagram. (Reference 3)

SECTION 3

TEST PLAN

The objective of this test program was to quantify emissions from a low NO_x design, oil-fired residential heating unit under both continuous and cyclical operation. The procedures for unit operation, sampling, and analysis follow.

3.1 UNIT OPERATION

In this test program, the major operating variable was the firing cycle frequency. Since the fuel pump and the combustion air fan operate from the same shaft, there was no way to vary fuel and air flows independently. Thus excess air levels remained approximately constant for the tests.

The continuous operation test required continuous firing of the unit for the duration of the test. The cycling operation test was to use a 10 minute "on" period. The "off" period was to be as short as possible while reasonably duplicating the 20 minute "off" period used in other residential heating unit tests.

3.2 SAMPLING AND ANALYSIS

The sampling and analysis procedures used in this test program conform to a modified EPA Level 1 protocol (Reference 4). The purpose of

these screening procedures is "to obtain preliminary information, identify problem areas, and provide the basis for the prioritization of streams, components, and classes of materials for further consideration in the overall assessment. As such, the results of the sampling and corresponding analysis procedures are quantitative within a factor of 2 to 3" (Reference 4).

Modifications to the Level 1 protocol are listed below:

- Atomic absorption spectroscopy is used for selected trace elements instead of spark-source mass spectrometry.
- Gas chromatograph/mass spectrometry (GCMS) is used to identify and quantify polycyclic organic materials (POM) instead of low resolution mass spectrometry (LRMS).

These modifications were made to improve the quantitative aspects of the analyses. The methods used for particulate, sulfur species and the continuous monitors for NO, O_2, CO, and CO_2 are also more quantitative than the Level 1 screening procedures for trace species.

3.2.1 Sampling

In order to evaluate changes in emissions, both influent and effluent streams must be analyzed. In this program, the following samples were collected:

- Fuel oil
- Flue gas (upstream of draft control)
  - -- Continuous monitors NO, CO, CO_2, O_2, hydrocarbons
  - -- Source Assessment Sampling System (SASS) and combined EPA Method 5 (particulate) and EPA Method 8 (sulfur species)
  - -- Grab sample for onsite analysis of C_1-C_6 hydrocarbons by gas chromatography

A schematic showing sampling point locations is given in Figure 3-1. Descriptions of the sampling methods are given in the following paragraphs.

Fuel Oil Samples

A fuel oil sample was collected at the furnace inlet. Since the firing rate was low, 2.27 liters per hour (0.6 gallons per hour), and all of the fuel came from one tank, one sample was sufficient to characterize the fuel oil for the test program.

Particulate and Sulfur Species

Combined EPA Methods 5 and 8 sampling trains using Acurex High Volume Stack Sampler (HVSS) systems were used to obtain particulate loading and sulfur species concentrations at the unit outlet, upstream of the draft control. The sulfur species determined were gaseous SO_2 and SO_3 and particulate sulfate ($SO_4^=$).

Source Assessment Sampling System

A Source Assessment Sampling System (SASS) train was used to sample the flue gas at the unit outlet. The SASS train samples were used for particulate loading, trace element and organic species determinations in both vapor and condensed phases, and also to provide trace element partitioning information. Normally the SASS train provides particle size distribution information but, in cases where the particulate loading is very low as in this test program, only the particulate filter is used.

The SASS train extracts the following samples:

Particulate: Filter catch

Vapor phase: XAD-2 porous polymer resin sorbent cartridge
Aqueous condensate
Hydrogen peroxide impinger
Ammonium persulfate - silver nitrate impingers

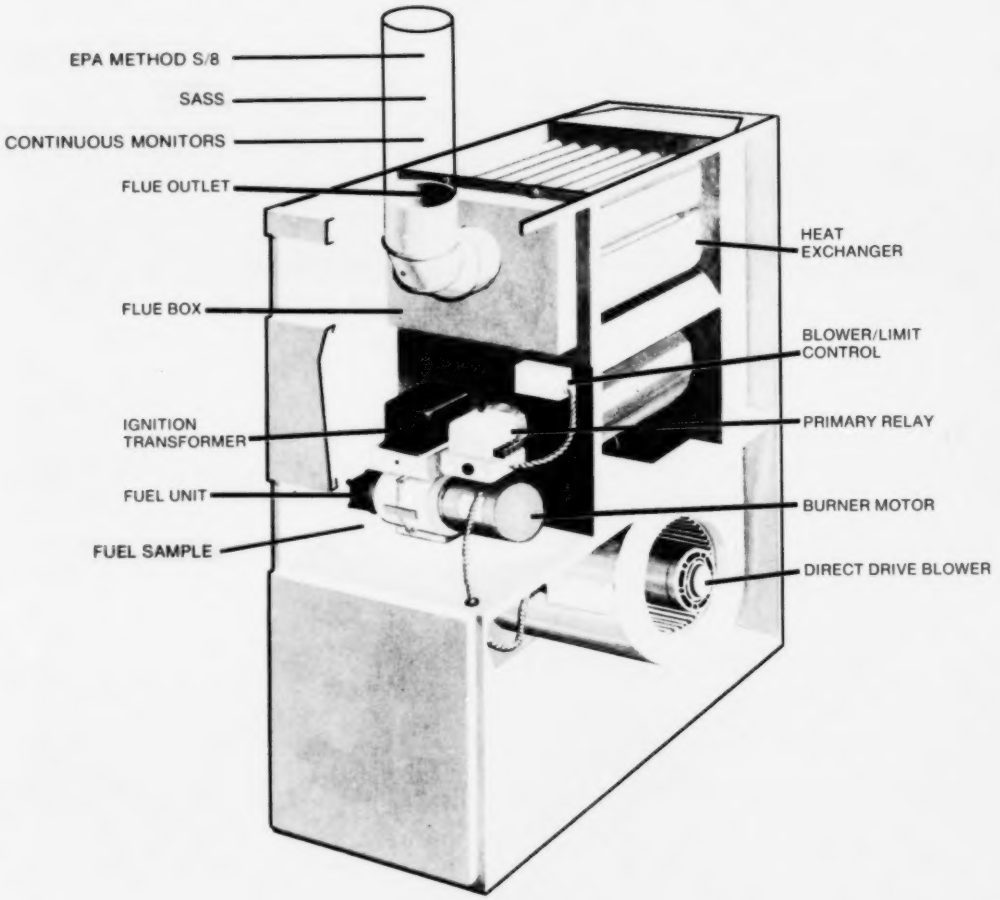

Figure 3-1. Sampling locations.

A schematic of the SASS train is shown in Figure 3-2. The analysis protocol is given in Appendix A.

Flue Gas Continuous Monitors

The continuous monitors for flue gas analysis were furnished by EPA in their mobile sampling trailer. The gas samples were taken from a point in the ductwork between the unit outlet and the draft regulator and were taken continuously during each test. A description of the instrumentation in the EPA sampling trailer is given in Table 3-1.

C_1-C_6 Hydrocarbons

A gas grab sample was collected between the unit outlet and the draft regulator. The sample was collected in a Tedlar bag and then used to determine C_1-C_6 hydrocarbon compounds by using an onsite gas chromatograph. A Carle model 8500 portable gas chromatograph with a flame ionization detector was used for this analysis.

3.2.2 Analysis

Table 3-2 lists the analyses performed on the samples collected during each test. Descriptions of these analyses are given in the following paragraphs.

Inorganic Analyses

Trace element analyses for 25 selected trace elements were performed on fuel, SASS flyash, and SASS impinger solutions. The procedure used for each trace element is outlined in Appendix A, "Elemental Analysis Flowsheet." An ultimate analysis was also conducted on the fuel sample.

Organic Analyses

Organic analyses were performed in accordance with the EPA Level 1 protocol (References 4 and 6). The analyses included flue gas C_1-C_6

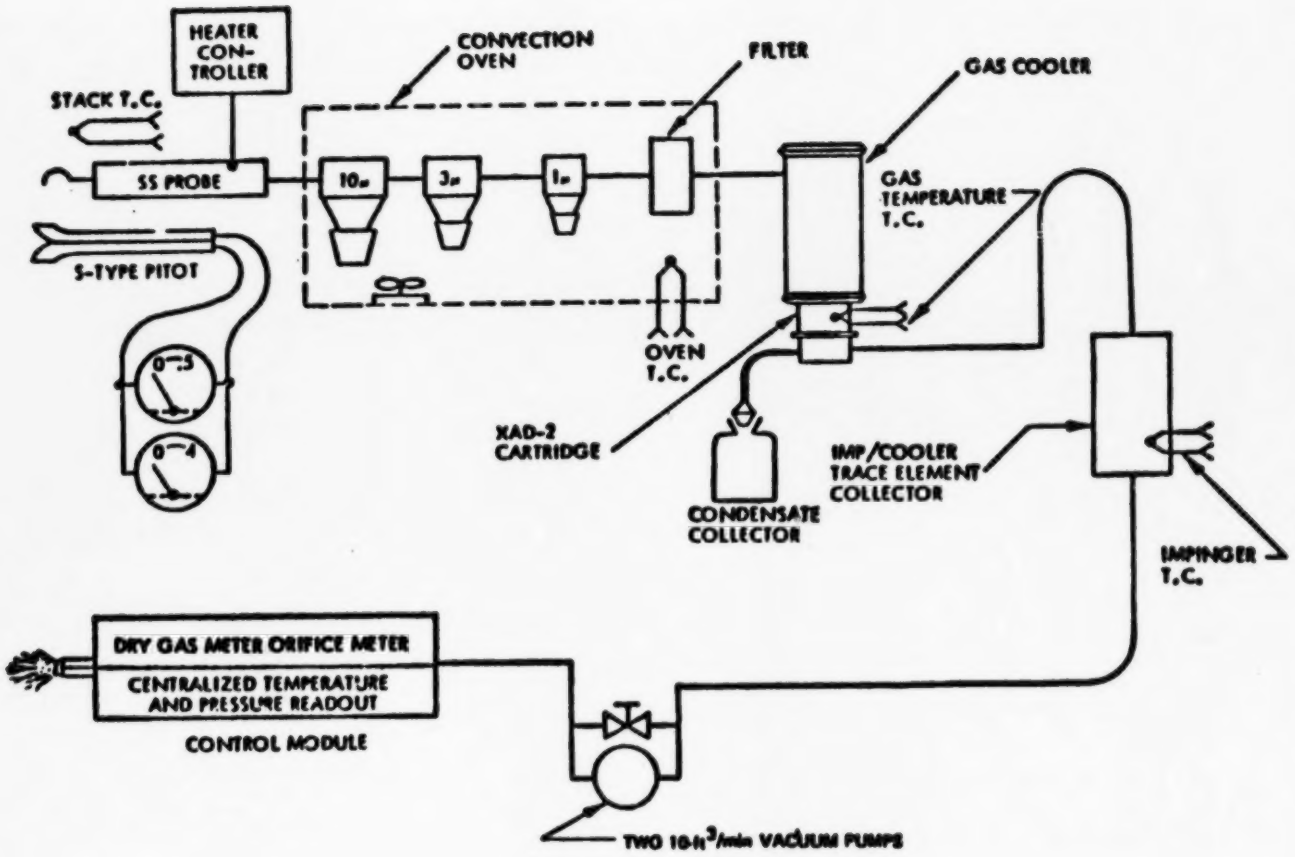

Figure 3-2. SASS train schematic (Reference 5).

TABLE 3-1. CONTINUOUS MONITOR EQUIPMENT IN EPA TRAILER

NO -- Thermoelectron	Chemiluminescent
O_2 -- Beckman	Paramagnetic
CO -- Beckman	Nondispersive infrared
CO_2 -- Beckman	Nondispersive infrared
Total Hydrocarbons -- Beckman	Flame ionization detector

TABLE 3-2. SAMPLE ANALYSIS SCHEDULE

Test	Cycling	Continuous
Fuel (composite sample)		
Ultimate	X	X
Trace elements	X	X
Method 5/8	X	X
SASS Train		
Trace elements	X	X
Organic material	X	X
Flue gas		
NO, CO, CO_2, O_2, HC	X	X
C_1-C_6	X	X

hydrocarbons, and organic material caught in the XAD-2 sorbent trap or retained in the condensate trap. An outline of the organic analyses procedures is given in Appendix A.

SECTION 4

TEST PROGRAM RESULTS

Data from the test program provided information on unit operation, flue gas composition, particulate emissions, trace element emissions, sulfur species emissions, and organic material emissions. Data obtained are discussed in the report sections that follow.

4.1 UNIT OPERATION

The test program was conducted under two different firing modes, cyclical and continuous operation. By comparing results of these two tests, the effects of cyclic on-off transients on emissions can be evaluated.

The Blueray furnace uses constant fuel and air flowrates, since both the combustion air fan and the fuel pump are driven by the same shaft. The only adjustments made to the unit were those required to regulate the firing cycles. The fuel used in the test was a distillate oil with low ash and sulfur content. The fuel analysis is given in Table 4-1.

The cycling test was run on a 10 minutes "on", 10 minutes "off" cycle. The 10 minutes "on" period was selected to approximate normal operation and because it compares to other residential heating system test programs (Reference 7). The "off" period was selected to minimize test duration while obtaining representative data. Flue gas temperature as a function of time was plotted for a 10 minute "on", 20 minute "off" cycle, and a 10 minute "on", 10 minute "off" cycle. As Figure 4-1 shows,

TABLE 4-1. FUEL ANALYSIS

	% By Weight
Carbon	86.11
Hydrogen	12.90
Nitrogen	0.27[a]
Sulfur	0.19
Ash	<0.01
Oxygen (by difference)	0.53
High heating value KJ/kg (Btu/lb)	44768 19265

[a]This value is high for distillate oil

the flue gas temperature at the end of the 10 minute "off" period is approaching the flue gas temperature at the end of the 20 minute "off" period. For the cycling test, then, a 10 minute "on", 10 minute "off" cycle was chosen. This cycle reduced the time for the SASS test to 8 hours.

The flue gas temperature during the cycling test went from an average start temperature of 323.5K (123^{o}F) to 493.5K (429^{o}F). The average temperature after 5 minutes of operation was 469.5K (386^{o}F). During the continuous operation test, the flue gas temperature reached an average value of 513K (464^{o}F) after 1 hour of operation. After reaching this average value, the temperature varied from 510K to 521K (459-479^{o}F). The difference in flue gas temperature between the two tests shows that system temperature equilibrium is not reached during normal cycling operation. Thus efficiency is lowered by the cycling operation by always having to warm up the heating unit.

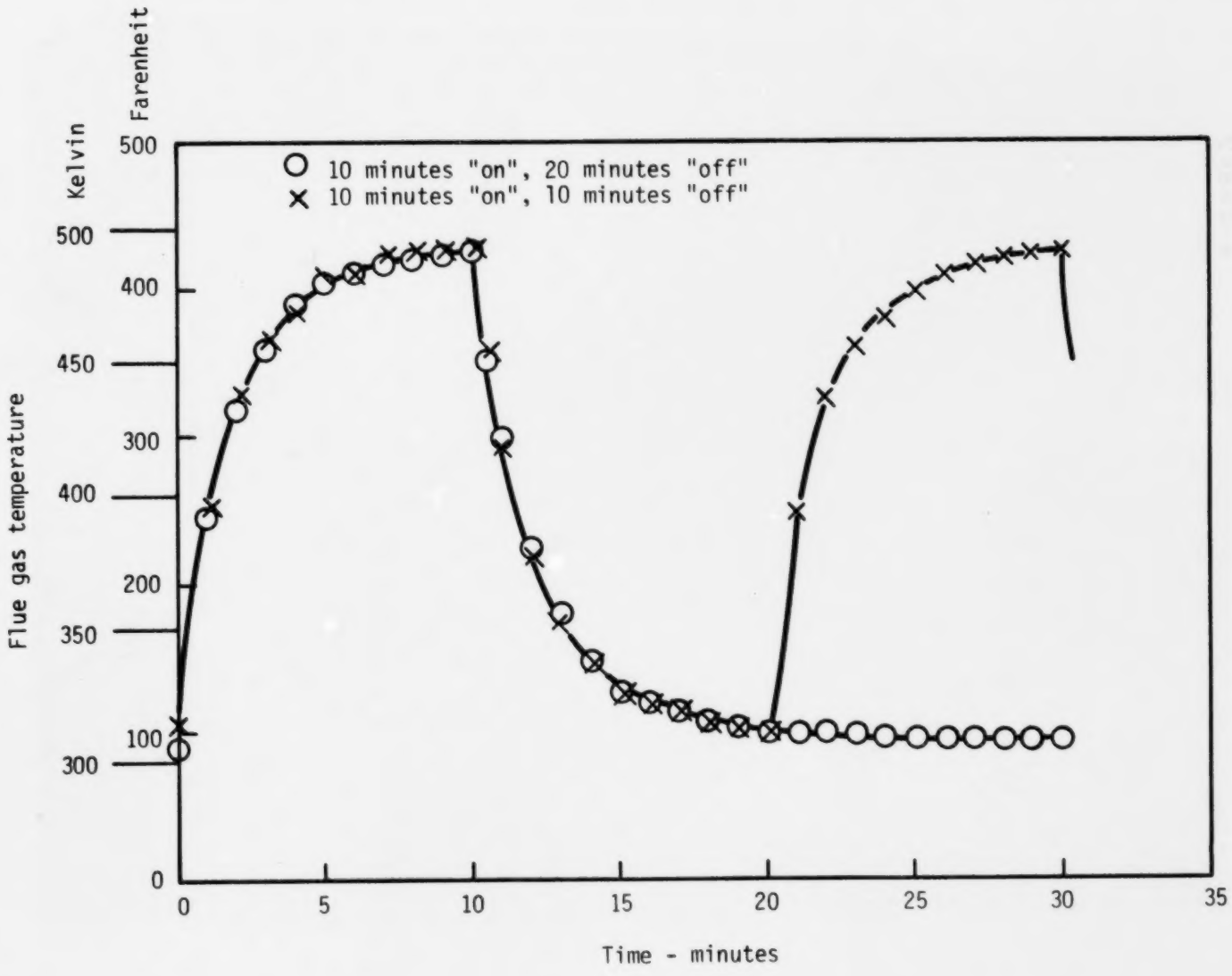

Figure 4-1. Flue gas temperature versus time.

4.2 FLUE GAS COMPOSITION

Table 4-2 lists the average concentrations of CO, CO_2, O_2, NO, and hydrocarbons in the flue gas during the period of firing. In the cycling test, there were peaks in the CO and hydrocarbon emissions at the start and end of each period of operation. The peak at the start is included in the average concentration. Since the blower and the fuel pump were on the same shaft, there is no forced air flow when the fuel is shut off. Since the air flowrate is unknown, the CO and hydrocarbon concentrations at the end of the firing cycle cannot be evaluated. For this reason, the effects on emissions of unit shut-off were not evaluated. Start-up peak emissions averaged 2000 ppm of CO and 400 ppm for hydrocarbons. The NO levels started at 0 and, toward the end of the firing cycle, reached 16 ppm which was the average value for the continuous firing test. Figure 4-2 shows representative flue gas composition changes during the cyclic operation test.

The average NO emissions are very low in both the cyclic and continuous operation tests. The start up effects do cause significantly higher CO and hydrocarbon emissions for the cyclic operation mode.

4.3 PARTICULATE EMISSIONS

Particulate emissions were measured by both EPA Method 5 and SASS techniques. The particulate concentrations measured by both methods are given in Table 4-3. Since the concentrations were so low, the particulate size distribution data were not obtained by the SASS train. The data on Table 4-3 show that while the SASS data differ from the Method 5 data, the results of each test type are very consistent. Particulate emissions are very low and do not vary from continuous operation to cyclic operation.

TABLE 4-2. FLUE GAS COMPOSITION

	Cyclic	Continuous
O_2 (percent dry)	4.0	3.8
CO_2 (percent dry)	12.9	13.1
H_2O (percent)	10.1	9.7
CO (ppm dry) (ng/J)	160 (59)	25 (9)
NO (ppm dry) (ng/J as NO_2)	11 (7)	16 (10)
Hydrocarbons (ppm dry) (ng/J as CH_4)	23 (5)	0 (0)

TABLE 4-3. PARTICULATE EMISSIONS

	ng/J	mg/dscm
Cyclic Operation		
Method 5	1.30	4.49
SASS	0.82	2.84
Continuous Operation		
Method 5	1.32	4.46
SASS	0.87	2.95

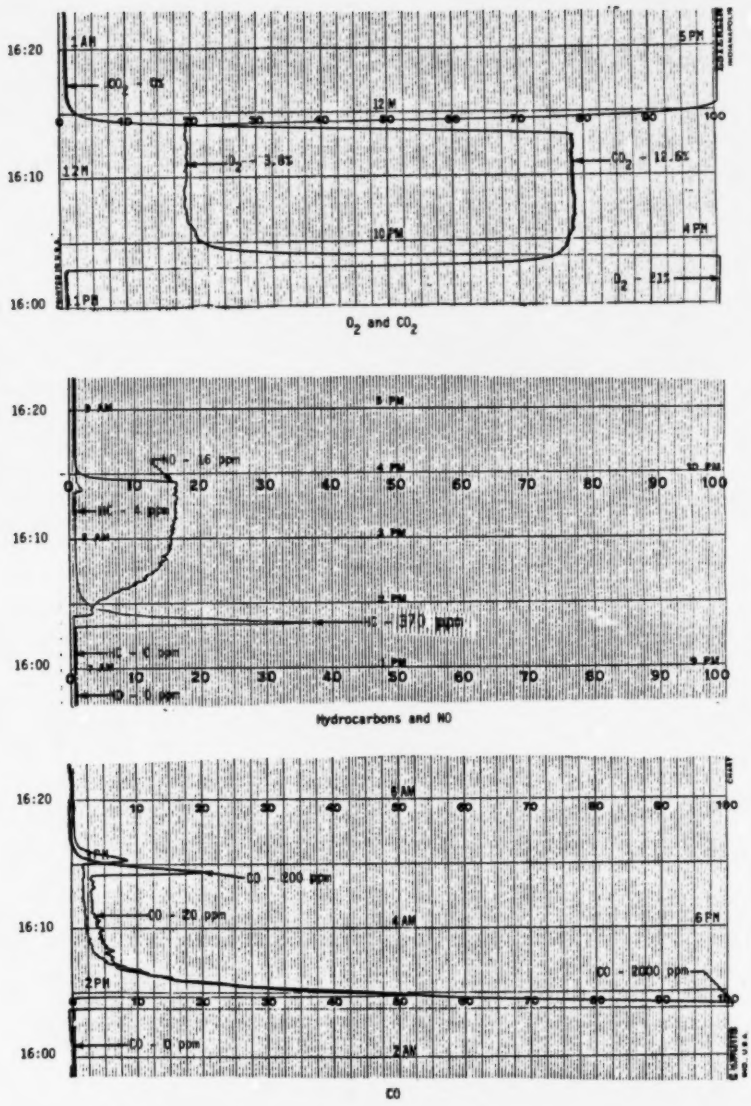

Figure 4-2. Flue gas composition vs. time during cyclical operation.

The low particulate emission levels are expected with the efficient combustion by the Blueray burner and the low ash content of the fuel oil.

4.4 TRACE ELEMENT CHARACTERIZATION AND EMISSIONS

The fuel sample from the inlet to the furnace and SASS train samples from the furnace outlet were analyzed for 25 selected trace elements. The detailed results of these analyses are presented in Appendix B. Once the trace element concentrations were determined, trace element flowrates for the fuel inlet, flue gas vapor phase, and flue gas condensed phase streams could be computed. The trace element flowrates are presented in Appendix C.

Some problems were experienced in analyzing the fuel and particulate samples. Since the distillate fuel oil is relatively free of mineral matter and process contaminants, several of the trace elements, if present, were present at lower than detectable levels. With the small amount of particulate matter available, even in the 30 m^3 SASS train sample, many of the trace elements were not present above the detectable levels. With small sample quantities, as is the case with the particulate samples, the detectability levels for the analyses are higher than one would prefer. The tests were long: 5 hours for the continuous operation test and 8.5 hours for the cycling operation test. The effectiveness of the oxidizing agents in the SASS impinger train is suspect in tests of such long duration. Thus some vapor phase trace element concentrations appear to be too low when compared to the fuel analysis. However, sufficient information was available to characterize the emissions of many of the trace species.

The partitioning of trace elements between vapor phase and condensed phase flue gas samples may be examined by comparing the trace

element flowrates in Appendix C. As shown on Table 4-4, some trace elements are concentrated in either the vapor or the condensed phase. Also, continuous operation does not cause the preferential concentrating tendencies to change from those exhibited under cyclical operation. Those elements found to concentrate in the condensed phase samples were barium, copper, and titanium. Those elements found to concentrate in the vapor phase samples were boron, chromium, cobalt, iron, lead, manganese, mercury, molybdenum, nickel, selenium, tin, and zinc. The chromium, iron, and nickel vapor phase concentrations are suspect since they may be due to the leaching of these elements from the stainless steel condensate trap of the SASS train organics module. A higher concentration of nickel and chromium was found in the outlet stream than in the inlet stream.

A trace element mass balance was constructed and is shown in Table 4-5. As expected, the resulting small particulate sample size and the suspected loss of effectiveness of the impinger train are reflected in the mass balance closure.

To improve test data on any subsequent tests where the trace element levels are low, some suggestions are made on the sampling methods.

- After 4 hours, the impinger train should be bypassed. This would allow vapor phase data to reflect the effective life of the impinger train solutions. Larger particulate and organics module samples could be collected and evaluated based on the larger gas volume sampled.
- Perform replicate analyses of fuel samples to provide a better basis for the mass balance

TABLE 4-4. TRACE ELEMENT PARTITIONING -- CONDENSED PHASE/VAPOR PHASE

	Cycling	Continuous
Antimony	X	X
Arsenic	X	X
Barium	C	C
Beryllium	X	X
Bismuth	X	X
Boron	V	X
Cadmium	X	X
Chromium	V	V
Cobalt	X	V
Copper	C	C
Iron	E	V
Lead	V	V
Manganese	X	V
Mercury	X	V
Molybdenum	V	V
Nickel	V	V
Selenium	V	V
Tellurium	X	X
Thallium	X	X
Tin	V	V
Titanium	X	C
Uranium	X	X
Vanadium	X	X
Zinc	V	V
Zirconium	X	X

C -- Concentrated in condensed phase
V -- Concentrated in vapor phase
E -- Concentrated equally in condensed and vapor phase
X -- Insufficient data

TABLE 4-5. ELEMENTAL MASS BALANCE (Out/In)

	Cycling	Continuous
Antimony	X	X
Arsenic	X	X
Barium	0.004	0.003
Beryllium	X	X
Bismuth	<0.004	<0.004
Boron	X	X
Cadmium	<0.90	<1.4, >1.2
Chromium	0.39	5.6
Cobalt	X	X
Copper	<0.09, >0.05	<0.11, >0.05
Iron	<0.09, >0.08	0.78
Lead	<0.78, >0.007	<0.73, >0.09
Manganese	<0.013, >0.003	<0.05, >0.04
Mercury	X	X
Molybdenum	X	X
Nickel	X	X
Selenium	X	X
Tellurium	<0.2	<0.17
Thallium	X	X
Tin	<0.09, >0.06	<0.06, >0.04
Titanium	<0.002	< 0.005, >0.004
Uranium	X	X
Vanadium	X	X
Zinc	<0.004, >0.002	<0.004, >0.002
Zirconium	X	X

4.5 SULFUR SPECIES EMISSIONS

Sulfur species were analyzed in the fuel and in the flue gas according to the following protocol:

- Fuel -- sulfur by ultimate analysis
- Flue gas upstream of draft regulator -- SO_2 and SO_3 by EPA Method 8 and sulfate on particulate by turbidimetric method

The results of the sulfur species analyses are presented in Table 4-6. As shown in this table, there was poor recovery of the sulfur by the Method 8 sampling train. Conclusions regarding SO_2 and SO_3 concentrations in the flue gas can not be drawn from these data. The probable cause for the poor sulfur recovery is that the tests took so long the hydrogen peroxide solution in the Method 8 impinger train became ineffective.

4.6 ORGANIC ANALYSIS

Organic analyses were performed on selected samples according to the EPA Level 1 protocol outlined in Appendix A (Reference 2 and 4). The samples were extracted with methylene chloride in a Soxhlet apparatus. The extracts were then subjected to total chromatographable organic (TCO) and gravimetric analyses which determine species with boiling points in the ranges of 373K to 573K and greater than 573K. Infrared spectra were also performed. If certain TCO and gravimetric requirements were met, further analyses were performed by liquid column chromatography, with infrared and mass spectral analyses of the fractions eluted from the column. The XAD-2 extract and the organic module condensate extract were

TABLE 4-6. SULFUR SPECIES ANALYSES RESULTS

Test		Continuous	Cycling
Heat Input	KW	23.3	23.3
Oil-Sulfur	% (ng/J)	0.19 (42.4)	0.19 (42.4)
Flue gas - Method 8 Particulate-Sulfate	mg/g (ng/J)	0 (0)	0 (0)
SO_2	mg/dscm[a] (ng/J)	92.7 (26.9)	120.7 (35.5)
SO_3	mg/dscm[a] (ng/J)	0.8 (0.2)	3.4 (1.0)
Sulfur Balance out/in	%	31.9	42.8

[a]3% O_2

combined into one sample of analysis. There was not enough particulate to perform organic analyses in addition to the trace element analyses. Flue gas C_1 to C_6 hydrocarbon compounds were analyzed onsite by gas chromatography. A discussion of the analytical results follows.

4.6.1 Total Chromatographable Organics (TCO) and Gravimetric Analyses of Organic Extracts

Total chromatographable organics and gravimetric analyses were performed on organic extracts from the continuous and cyclical operation tests. The samples analyzed were the combined XAD-2 extracts and organic module condensate extracts. The results of these analyses are presented in Table 4-7. The results show that organic emissions in the continuous operation test were 1.3 mg/m^3. The cyclical operation test had a much higher organic emission level of 26.3 mg/m^3. These results indicate that cyclic operation causes a large increase in organic emissions.

To qualify for liquid column separation, a sample was required to contain at least 15 mg organic material. Both samples qualified for this procedure and were separated for further analysis.

4.6.2 Infrared Spectra of Total Extracts

The results of the infrared spectra determinations for the total extract samples are summarized in Table 4-8. The spectra showed the presence of aliphatic hydrocarbons, aromatic compounds and carboxylic acid.

4.6.3 Column Chromatography

The sample extracts were concentrated and fractionated according to Level 1 procedures (References 4 and 6). TCO and gravimetric content for each fraction were then obtained. These data are presented in Table 4-9.

TABLE 4-7. RESULTS AND GRAVIMETRIC ANALYSES OF TOTAL EXTRACT SAMPLES

Test	Sample	Gravimetric Results (mg)	TCO Results (mg)	Total Organics in Sample (mg)	Concentration in Flue Gas mg/m^3
Cyclical	XAD-2 Extract and Organic Module Condensate Extract	88.6	682.8	771.4	26.3
Continuous	XAD-2 Extract and Organic Module Concentrate Extract	10.5	33.2	43.7	1.3

TABLE 4-8. SUMMARY OF INFRARED SPECTRA OF TOTAL EXTRACT SAMPLES

Test	Sample Type	Summary of Spectra
Cycling	XAD-2 Extract	Carboxylic acid, aliphatic hydrocarbons, some aromatics present
	Organic Module Condensate Extract	Carboxylic acid, aliphatic hydrocarbons, some aromatics present
Continuous	XAD-2 Extract	Carboxylic acid, aliphatic hydrocarbons, some aromatics present
	Organic Module Condensate Extract	Carboxylic acid, aliphatic hydrocarbons, some aromatics present

TABLE 4-9. RESULTS OF TCO AND GRAVIMETRIC ANALYSES FROM COLUMN CHROMATOGRAPHY OF ORGANIC EXTRACTS

	LC 1	LC 2	LC 3	LC 4	LC 5	LC 6	LC 7	Total
Cycling Operation								
TCO mg	77.5	26.3	<1.3	3.8	16.3	12.5	<1.3	136.4
Gravimetric mg	87.5	40.0	35.0	68.8	50.0	215.0	98.8	595.1
Total mg	165.0	66.3	35.0	72.6	66.3	227.5	98.8	731.5
(mg/m^3)	5.6	2.3	1.2	2.5	2.3	7.8	3.4	25.1
Continuous Operation								
TCO mg	3.4	<0.1	1.4	2.8	0.6	0.1	<0.1	8.3
Gravimetric mg	<0.1	<0.1	<0.1	7.8	9.6	10.4	9.0	36.8
Total mg	3.4	<0.1	1.4	10.6	10.2	10.5	9.0	45.1
(mg/m^3)	0.1	<0.1	<0.1	0.3	0.3	0.3	0.3	1.3

4.6.4 Infrared and Mass Spectral (LRMS and GC/MS) Analyses of Fractions from Column Chromatography

The samples obtained from the column chromatography fractionation were split and infrared spectra were determined. For the cyclical operation test samples, low resolution mass spectrometry (LRMS) analyses following Level 1 procedures (Reference 4 and 6) were performed. The fractions from the continuous operation test sample did not contain a sufficient quantity of organic material to warrant LRMS analyses. The results of the analyses are given in Tables 4-10 through 4-13. Summary results are presented in Table 4-14. In addition, fractions 2 and 3 from the cyclical operation test were combined and subjected to analysis by gas chromatograph/mass spectrometry to identify and quantify specific polynuclear aromatic compounds. The results of this analysis are given in Table 4-15. As in the total extract analyses, the principal constituents were aliphatic hydrocarbons, carboxylic acid, and some aromatic compounds.

4.6.5 C_1 to C_6 Flue Gas Hydrocarbon Analysis

Onsite analyses of C_1 to C_6 flue gas hydrocarbons were conducted for both tests. The grab samples were taken during steady state operation, (5 minutes after startup in the cycling test) and also during a peak emission period in the cycling test. The results of these analyses are presented in Table 4-16. As shown in this table, steady state operation produces equivalent hydrocarbon emissions in each test while the peak hydrocarbon emissions during startup are considerably higher.

4.6.6 Summary of Organic Analyses

The organic emissions were much higher in the cycling operation test than in the continuous operation test. Most of the organic compounds are aliphatic hydrocarbons and are probably directly attributable to

TABLE 4-10. SUMMARY OF INFRARED AND LRMS ANALYSES -- FRACTION 1

Test	Summary of IR Spectra	Summary of LRMS
Cycling	Aliphatic hydrocarbons, possible ether present	Aliphatic hydrocarbons $C_n H_{2n+2}$ (major)
Continuous	Aliphatic hydrocarbons, trace of aromatics	Insufficient quantity for analysis

TABLE 4-11. SUMMARY OF INFRARED AND LRMS ANALYSES -- FRACTIONS 2 AND 3

Test	Summary of IR Spectra	Summary of LRMS
Cycling	Fraction 2 Aliphatic hydrocarbons	Combined Fractions 2 and 3 Aliphatic hydrocarbons $C_n H_{2n+2}$ (minor)
	Fraction 3 Aliphatic hydrocarbons, Aromatics present	Polycyclic organic compounds (see Table 4-15)
Continuous	Fraction 2 Aliphatic hydrocarbons	Insufficient quantity for analysis
	Fraction 3 Aliphatic hydrocarbons	

TABLE 4-12. SUMMARY OF INFRARED AND LRMS ANALYSES -- FRACTIONS 4 AND 5

Test	Summary of IR Spectra	Summary of LRMS
Cycling	Fraction 4 Either alcohol or acid and carbonyl, most likely an ester Fraction 5 Nothing visible in Spectrum	Combined Fractions 4 and 5 Aliphatic hydrocarbons $C_n H_{2n+2}$ (trace)
Continuous	Fraction 4 Aliphatic hydrocarbons Fraction 5 Alcohol (phenol), ester, and possible carboxylic acid present	Insufficient quantity for analysis

TABLE 4-13. SUMMARY OF INFRARED AND LRMS ANALYSES -- FRACTIONS 6 AND 7

Test	Summary of IR Spectra	Summary of LRMS
Cycling	Fraction 6 Carboxylic acid, aromatic rings apparent Fraction 7 Nothing visible in spectrum	Combined Fractions 6 and 7 Aliphatic hydrocarbons $C_n H_{2n+2}$ (trace)
Continuous	Fraction 6 Weak spectrum Fraction 7 No organics present	Insufficient quantity for analysis

TABLE 4-14. LEVEL 1 ORGANIC EXTRACT SUMMARY, CYCLING OPERATION

Fraction	TCO mg/m^3	Gravimetric mg/m^3	Total Organics mg/m^3	Compound Category	LRMS Intensity	Maximum Concentration mg/m^3
1	2.6	3.0	5.6	Aliphatic hydrocarbons	100	5.6
2 and 3	0.9	2.6	3.5	Aliphatic hydrocarbons	10	3.2
				Polycyclic organic compounds	1	0.3
4 and 5	0.7	4.0	4.7	Aliphatic hydrocarbons	1	4.7
6 and 7	0.4	10.7	11.1	Aliphatic hydrocarbons	1	11.1

TABLE 4-15. RESULTS OF QUANTITATION OF POLYCYCLIC ORGANIC COMPOUNDS, CYCLICAL OPERATION, ORGANIC EXTRACT FRACTIONS 2 AND 3

Compound	Molecular Weight	Quantity ng	Quantity ng/m^3
Phenanthrene/Anthracene	178	22500	767
Pyrene	202	250	9
Fluoranthene	202	750	26
Other polycyclic organic compounds sought, but not detected: Anthanthrene, Benzo(a)anthracene, Benzo(a)pyrene, Benzo(e)pyrene, Benzo(g,h,i)perylene, Perylene			

TABLE 4-16. C_1 TO C_6 FLUE GAS HYDROCARBON ANALYSIS (ppm-dry)

Test	Cycling		
	Continuous	Steady State	Peak
C_1 (Methane)	--	--	19
C_2 (Methane)	--	--	53
C_3 (Propane)	--	--	7
C_4 (Butane)	--	--	5
C_5 (Pentane)	62	57	3
C_6 (Hexane)	--	--	2

unburned fuel oil in the flue gas. This would be characteristic of poor ignition, poor mixing, and the quenching effect of a cold combustion chamber on startup. Some polycyclic organic compounds present in low concentrations were identified in the cyclic operation test. The infrared spectra indicated the presence of aromatic compounds in samples from both tests. In conclusion, there appeared to be the same material in samples from both tests. However, the quantities present in the cyclic operation test were much greater than in the continuous operation test.

SECTION 5

SUMMARY

The test program conducted on an oil-fired low-emission residential furnace compared emissions during continuous operation with those during cyclic operation. The emissions sampled were NO, CO, and unburned hydrocarbons by continuous monitors, C_1 to C_6 hydrocarbons by gas chromatograph, particulate by EPA Method 5 and SASS procedures, sulfur species by EPA Method 8, and trace elemental and organic species by SASS procedures.

The NO emissions were slightly higher in the continuous operation test. This difference was due to the combustion chamber reaching its steady state temperature. Similarly, CO and hydrocarbon emissions were higher in the cycling operation test because of the poor ignition and mixing and the quenching effect of the cold combustion chamber during startup.

The C_1 to C_6 hydrocarbon emissions were similar in the continuous and cycling tests after the transient conditions during startup had diminished. C_1 to C_6 emissions during the transient phase of the cycling operation were higher than the steady state emissions of either operating mode.

Particulate emissions were very similar during each test. Sulfur species tests were inconclusive. Trace element emissions appeared to be unaffected by changes in modes of operation. Finally, organic emissions levels were significantly higher in the cyclical operation test.

A general conclusion that longer heating cycles would improve efficiency and lower emissions can be made. The improved efficiency comes from having to warm up the heating system less frequently. Similarly, lowered organic material emissions, which would also indicate better fuel utilization, result from less frequent startup cycles.

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4. Hammersma, J. W., et al., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment," EPA-600/2-76-160a, (NTIS PB 257 850/AS), June 1976.

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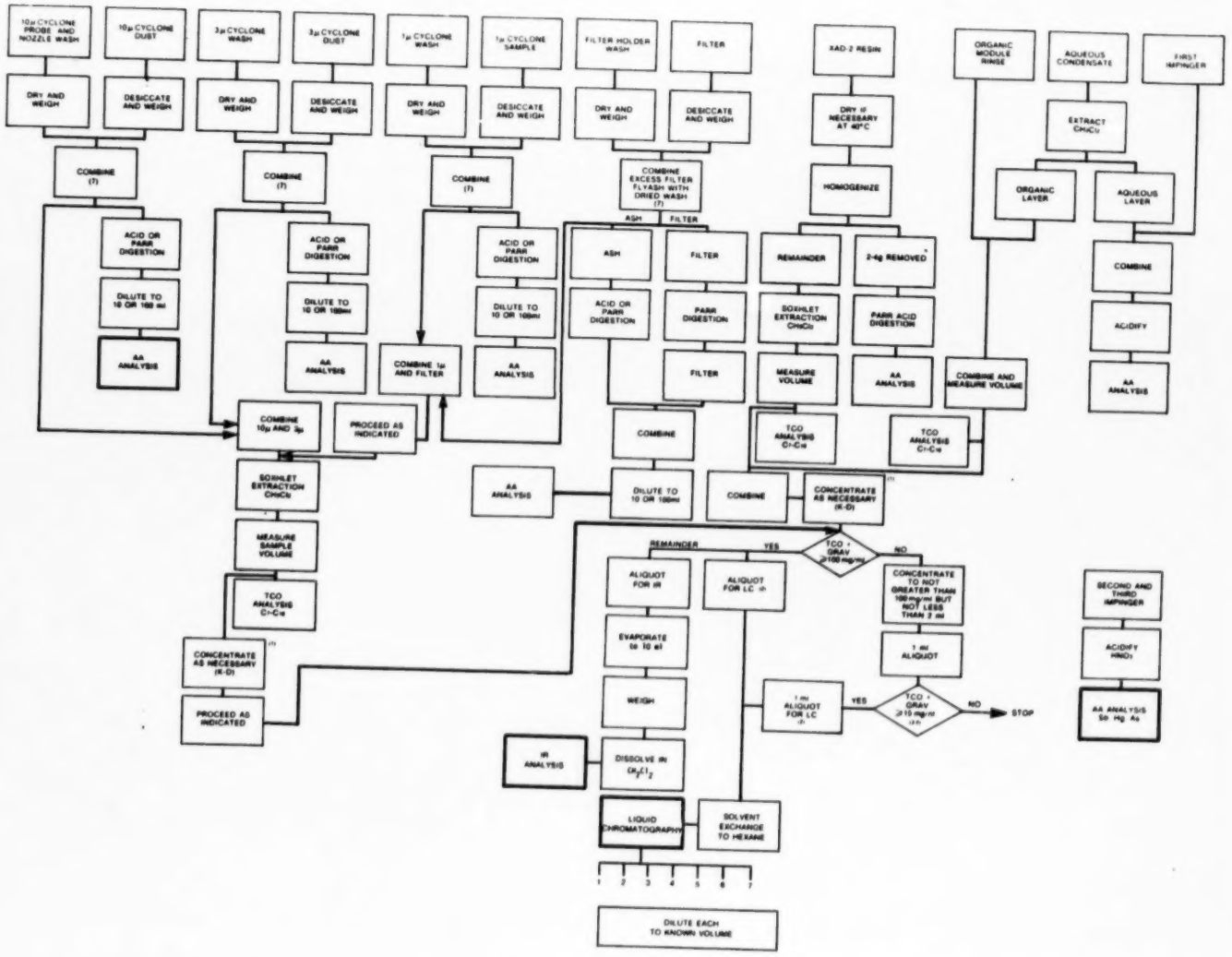
APPENDIX A

ANALYTICAL PROCEDURES



SASS analysis protocol.

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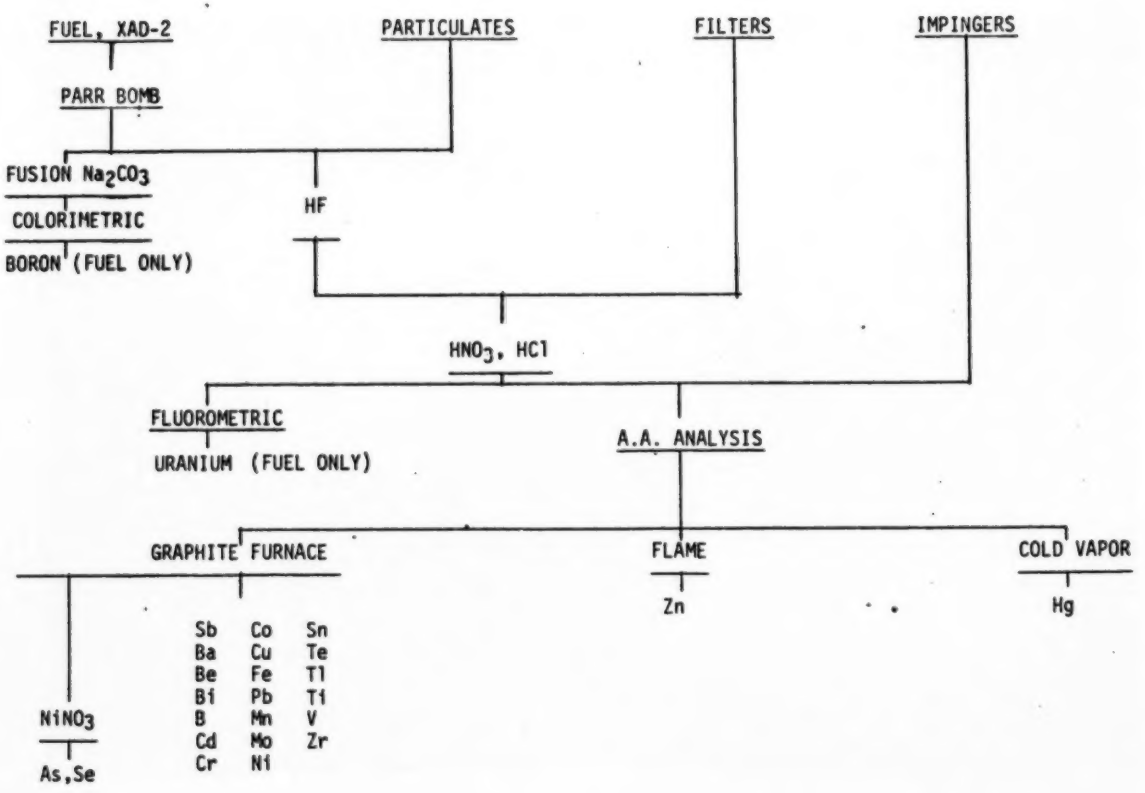
ELEMENTAL ANALYSIS FLOWSHEET



APPENDIX B

TRACE ELEMENT CONCENTRATIONS

Symbols appearing in the tables:

DSCM	Dry standard cubic meter
MCG	Microgram
PPM	Part per million by weight
SEC	Second
<	Less than
*	Sample not analyzed for the particular element

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RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT CONCENTRATION - (PPM) -FUEL

TRACE ELEMENT	TEST CONDITION	
	CYCLING	CONTINUOUS
ANTIMONY	< .400	< .400
ARSENIC	< .900	< .900
BARIUM	260.	260.
BERYLLIUM	< .100+00	< .100+00
BISMUTH	12.0	12.0
BORON	< 3.00	< 3.00
CADMIUM	.100+00	.100+00
CHROMIUM	1.20	1.20
COBALT	< .400-01	< .400-01
COPPER	11.0	11.0
IRON	42.0	42.0
LEAD	2.30	2.30
MANGANESE	17.0	17.0
MERCURY	< .400	< .400
MOLYBDENUM	< 2.00	< 2.00
NICKEL	< .900-01	< .900-01
SELENIUM	< .900-01	< .900-01
TELLURIUM	.300	.300
THALLIUM	< .200	< .200
TIN	.900	.900
TITANIUM	43.0	43.0
URANIUM	1.00	1.00
VANADIUM	< .200	< .200
ZINC	59.0	59.0
ZIRCONIUM	< 19.0	< 19.0

RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT CONCENTRATION - (PPM) -FUEL

TRACE ELEMENT	TEST CONDITION	
	CYCLING	CONTINUOUS
ANTIMONY	< .400	< .400
ARSENIC	< .900	< .900
BARIUM	260.	260.
BERYLLIUM	< .100+00	< .100+00
BISMUTH	12.0	12.0
BORON	< 3.00	< 3.00
CADMIUM	.100+00	.100+00
CHROMIUM	1.20	1.20
COBALT	< .400-01	< .400-01
COPPER	11.0	11.0
IRON	42.0	42.0
LEAD	2.30	2.30
MANGANESE	17.0	17.0
MERCURY	< .400	< .400
MOLYBDENUM	< 2.00	< 2.00
NICKEL	< .900-01	< .900-01
SELENIUM	< .900-01	< .900-01
TELLURIUM	.300	.300
THALLIUM	< .200	< .200
TIN	.900	.900
TITANIUM	43.0	43.0
URANIUM	1.00	1.00
VANADIUM	< .200	< .200
ZINC	59.0	59.0
ZIRCONIUM	< 19.0	< 19.0

RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT CONCENTRATION - (PPM) -UNIT OUTLET
FILTER DUST

TRACE ELEMENT	TEST CONDITION	
	CYCLING	CONTINUOUS
ANTIMONY	< 105.	< 77.2
ARSENIC	* .000	* .000
BARIUM	.110+05	.830+04
BERYLLIUM	< 3.30	< 2.40
BISMUTH	< 32.8	< 24.1
BORON	* .000	* .000
CADMIUM	< 3.30	< 2.41
CHROMIUM	.176+04	.203+04
COBALT	< 32.8	80.3
COPPER	.650+04	.940+04
IRON	.240+05	.290+05
LEAD	198.	.250+04
MANGANESE	505.	.117+04
MERCURY	* .000	* .000
MOLYBDENUM	451.	420.
NICKEL	.184+04	.140+04
SELENIUM	3.60	< .300
TELLURIUM	< 91.8	< 62.0
THALLIUM	< 3.30	< 2.41
TIN	< 1.00	< 1.00
TITANIUM	< 328.	.188+04
URANIUM	* .000	* .000
VANADIUM	< 538.	< 39.6
ZINC	< 32.8	< 24.1
ZIRCONIUM	* .000	* .000

RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT CONCENTRATION - (PPM) -UNIT OUTLET
XAD-2 CARTRIDGE

TRACE ELEMENT	TEST CONDITION	
	CYCLING	CONTINUOUS
ANTIMONY	< .300	< .300
ARSENIC	< .400	< .400
BARIUM	< .800-01	< .900-01
BERYLLIUM	< .100-01	< .100-01
BISMUTH	< .500	< .600
BORON	12.0	< 4.00
CADMIUM	< 1.00	2.00
CHROMIUM	.250	1.00
COBALT	< 5.00	< 6.00
COPPER	< 5.00	< 5.00
IRON	< 4.00	< 5.00
LEAD	< 20.0	< 20.0
MANGANESE	< 2.00	< 3.00
MERCURY	< 1.00	4.50
MOLYBDENUM	< .700	< .800
NICKEL	< 5.00	7.00
SELENIUM	< .300	< .300
TELLURIUM	< .600	< .600
THALLIUM	< 40.0	< 40.0
TIN	< .300	.600
TITANIUM	< .600	< .600
URANIUM	* .000	* .000
VANADIUM	< .600	< .700
ZINC	< 2.00	< 2.00
ZIRCONIUM	* .000	* .000

RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT CONCENTRATION - (PPM) -UNIT OUTLET
1ST IMPINGER

TRACE ELEMENT	TEST CONDITION	
	CYCLING	CONTINUOUS
ANTIMONY	< .300-02	< .290-02
ARSENIC	< .670-02	< .720-02
BARIUM	.440-02	< .700-03
BERYLLIUM	< .100-03	< .100-03
BISMUTH	< .670-02	< .720-02
BORON	* .000	* .000
CADMIUM	< .100-01	< .110-01
CHROMIUM	.160	4.30
COBALT	< .670-01	.110
COPPER	< .340-01	.720-01
IRON	.810	20.0
LEAD	< .200	< .180
MANGANESE	< .170-01	.430
MERCURY	.940-01	< .250-01
MOLYBDENUM	.110	.540
NICKEL	.210	3.20
SELENIUM	.670-01	.110
TELLURIUM	< .670-02	< .720-02
THALLIUM	< .340	< .360
TIN	.300-01	< .140-01
TITANIUM	< .670-02	< .720-02
URANIUM	* .000	* .000
VANADIUM	< .340-02	< .360-02
ZINC	.510-01	.900-01
ZIRCONIUM	* .000	* .000

RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT CONCENTRATION - (PPM) -UNIT OUTLET
2ND - 3RD IMPINGER

TRACE ELEMENT	TEST CONDITION	
	CYCLING	CONTINUOUS
ANTIMONY	.300-02	< .100-02
ARSENIC	.500-02	< .200-02
BARIUM	* .000	* .000
BERYLLIUM	* .000	* .000
BISMUTH	* .000	* .000
BORON	* .000	* .000
CADMIUM	* .000	* .000
CHROMIUM	* .000	* .000
COBALT	* .000	* .000
COPPER	* .000	* .000
IRON	* .000	* .000
LEAD	* .000	* .000
MANGANESE	* .000	* .000
MERCURY	< .200-02	.200-02
MOLYBDENUM	* .000	* .000
NICKEL	* .000	* .000
SELENIUM	* .000	* .000
TELLURIUM	* .000	* .000
THALLIUM	* .000	* .000
TIN	* .000	* .000
TITANIUM	* .000	* .000
URANIUM	* .000	* .000
VANADIUM	* .000	* .000
ZINC	* .000	* .000
ZIRCONIUM	* .000	* .000

APPENDIX C

TRACE ELEMENT FLOWRATES

Symbols appearing in the tables:

DSCM	Dry standard cubic meter
MCG	Microgram
PPM	Part per million by weight
SEC	Second
<	Less than
*	Sample not analyzed for the particular element

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APPENDIX C-1

TRACE ELEMENT FLOWRATES

(micrograms per second)

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RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT ANALYSIS - (MCG/SEC) -FUEL

TRACE ELEMENT	TEST CONDITION	
	CYCLING	CONTINUOUS
ANTIMONY	< .219	< .219
ARSENIC	< .492	< .492
BARIUM	142.	142.
BERYLLIUM	< .547-01	< .547-01
BISMUTH	6.56	6.56
BORON	< 1.64	< 1.64
CADMIUM	.547-01	.547-01
CHROMIUM	.656	.656
COBALT	< .219-01	< .219-01
COPPER	6.02	6.02
IRON	23.0	23.0
LEAD	1.26	1.26
MANGANESE	9.30	9.30
MERCURY	< .219	< .219
MOLYBDENUM	< 1.09	< 1.09
NICKEL	< .492-01	< .492-01
SELENIUM	< .492-01	< .492-01
TELLURIUM	.164	.164
THALLIUM	< .109	< .109
TIN	.492	.492
TITANIUM	23.5	23.5
URANIUM	.547	.547
VANADIUM	< .109	< .109
ZINC	32.3	32.3
ZIRCONIUM	< 10.4	< 10.4

RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT ANALYSIS - (MCG/SEC) -UNIT OUTLET
FILTER DUST

TRACE ELEMENT	TEST CONDITION	
	CYCLING	CONTINUOUS
ANTIMONY	< .484-02	< .339-02
ARSENIC	* .000	* .000
BARIUM	.508	.365
BERYLLIUM	< .152-03	< .105-03
BISMUTH	< .151-02	< .106-02
BORON	* .000	* .000
CADMIUM	< .152-03	< .106-03
CHROMIUM	.812-01	.893-01
COBALT	< .151-02	.353-02
COPPER	.300	.413
IRON	1.11	1.27
LEAD	.912-02	.110
MANGANESE	.233-01	.513-01
MERCURY	* .000	* .000
MOLYBDENUM	.208-01	.185-01
NICKEL	.847-01	.615-01
SELENIUM	.166-03	< .132-04
TELLURIUM	< .424-02	< .272-02
THALLIUM	< .152-03	< .106-03
TIN	< .462-04	< .439-04
TITANIUM	< .151-01	.825-01
URANIUM	* .000	* .000
VANADIUM	< .248-01	< .174-02
ZINC	< .151-02	< .106-02
ZIRCONIUM	* .000	* .000

RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT ANALYSIS - (MCG/SEC) -UNIT OUTLET
XAD-2 CARTRIDGE

TRACE ELEMENT	TEST CONDITION	
	CYCLING	CONTINUOUS
ANTIMONY	< .116-01	< .985-02
ARSENIC	< .154-01	< .131-01
BARIUM	< .309-02	< .296-02
BERYLLIUM	< .386-03	< .328-03
BISMUTH	< .193-01	< .197-01
BORON	.463	< .131
CADMIUM	< .386-01	.657-01
CHROMIUM	.964-02	.328-01
COBALT	< .193	< .197
COPPER	< .193	< .164
IRON	< .154	< .164
LEAD	< .771	< .657
MANGANESE	< .771-01	< .985-01
MERCURY	< .386-01	.148
MOLYBDENUM	< .270-01	< .263-01
NICKEL	< .193	.230
SELENIUM	< .116-01	< .985-02
TELLURIUM	< .231-01	< .197-01
THALLIUM	< 1.54	< 1.31
TIN	< .116-01	.197-01
TITANIUM	< .231-01	< .197-01
URANIUM	* .000	* .000
VANADIUM	< .231-01	< .230-01
ZINC	< .771-01	< .657-01
ZIRCONIUM	* .000	* .000

RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT ANALYSIS - (NCG/SEC) -UNIT OUTLET
1ST IMPINGER

TRACE ELEMENT	TEST CONDITION	
	CYCLING	CONTINUOUS
ANTIMONY	< .312-02	< .240-02
ARSENIC	< .697-02	< .596-02
BARIUM	.457-02	< .580-03
BERYLLIUM	< .104-03	< .828-04
BISMUTH	< .697-02	< .596-02
BORON	* .000	* .000
CADMIUM	< .104-01	< .911-02
CHROMIUM	.166	3.56
COBALT	< .697-01	.911-01
COPPER	< .353-01	.596-01
IRON	.842	16.6
LEAD	< .208	< .149
MANGANESE	< .177-01	.356
MERCURY	.977-01	< .207-01
MOLYBDENUM	.114	.447
NICKEL	.218	2.65
SELENIUM	.697-01	.911-01
TELLURIUM	< .697-02	< .596-02
THALLIUM	< .353	< .298
TIN	.312-01	< .116-01
TITANIUM	< .697-02	< .596-02
URANIUM	* .000	* .000
VANADIUM	< .353-02	< .298-02
ZINC	.530-01	.745-01
ZIRCONIUM	* .000	* .000

RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT ANALYSIS - (MCG/SEC) -UNIT OUTLET
2ND - 3RD IMPINGER

TRACE ELEMENT	TEST CONDITION			
	CYCLING		CONTINUOUS	
ANTIMONY		.179-02	<	.534-03
ARSENIC		.298-02	<	.107-02
BARIUM	*	.000	*	.000
BERYLLIUM	*	.000	*	.000
BISMUTH	*	.000	*	.000
BORON	*	.000	*	.000
CADMIUM	*	.000	*	.000
CHROMIUM	*	.000	*	.000
COBALT	*	.000	*	.000
COPPER	*	.000	*	.000
IRON	*	.000	*	.000
LEAD	*	.000	*	.000
MANGANESE	*	.000	*	.000
MERCURY	<	.119-02		.107-02
MOLYBDENUM	*	.000	*	.000
NICKEL	*	.000	*	.000
SELENIUM	*	.000	*	.000
TELLURIUM	*	.000	*	.000
THALLIUM	*	.000	*	.000
TIN	*	.000	*	.000
TITANIUM	*	.000	*	.000
URANIUM	*	.000	*	.000
VANADIUM	*	.000	*	.000
ZINC	*	.000	*	.000
ZIRCONIUM	*	.000	*	.000

APPENDIX C-2

TRACE ELEMENT FLOWRATES

(micrograms per joule)

RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT ANALYSIS - (MCG/JOULE) -FUEL

TRACE ELEMENT	TEST CONDITION	
	CYCLING	CONTINUOUS
ANTIMONY	< .938-05	< .938-05
ARSENIC	< .211-04	< .211-04
BARIUM	.610-02	.610-02
BERYLLIUM	< .235-05	< .235-05
BISMUTH	.281-03	.281-03
BORON	< .704-04	< .704-04
CADMIUM	.235-05	.235-05
CHROMIUM	.281-04	.281-04
COBALT	< .938-06	< .938-06
COPPER	.258-03	.258-03
IRON	.985-03	.985-03
LEAD	.539-04	.539-04
MANGANESE	.399-03	.399-03
MERCURY	< .938-05	< .938-05
MOLYBDENUM	< .469-04	< .469-04
NICKEL	< .211-05	< .211-05
SELENIUM	< .211-05	< .211-05
TELLURIUM	.704-05	.704-05
THALLIUM	< .469-05	< .469-05
TIN	.211-04	.211-04
TITANIUM	.101-02	.101-02
URANIUM	.235-04	.235-04
VANADIUM	< .469-05	< .469-05
ZINC	.138-02	.138-02
ZIRCONIUM	< .446-03	< .446-03

RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT ANALYSIS - (MCG/JOULE) -UNIT OUTLET
FILTER DUST

TRACE ELEMENT	TEST CONDITION	
	CYCLING	CONTINUOUS
ANTIMONY	< .208-06	< .146-06
ARSENIC	* .000	* .000
BARIUM	.218-04	.157-04
BERYLLIUM	< .654-08	< .453-08
BISMUTH	< .650-07	< .455-07
BORON	* .000	* .000
CADMIUM	< .654-08	< .455-08
CHROMIUM	.348-05	.383-05
COBALT	< .650-07	.151-06
COPPER	.129-04	.177-04
IRON	.475-04	.547-04
LEAD	.392-06	.472-05
MANGANESE	.100-05	.220-05
MERCURY	* .000	* .000
MOLYBDENUM	.894-06	.793-06
NICKEL	.364-05	.264-05
SELENIUM	.713-08	< .566-09
TELLURIUM	< .182-06	< .117-06
THALLIUM	< .654-08	< .455-08
TIN	< .198-08	< .189-08
TITANIUM	< .649-06	.354-05
URANIUM	* .000	* .000
VANADIUM	< .106-05	< .747-07
ZINC	< .650-07	< .455-07
ZIRCONIUM	* .000	* .000

RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT ANALYSIS - (MCG/JOULE) -UNIT OUTLET
XAD-2 CARTRIDGE

TRACE ELEMENT	TEST CONDITION	
	CYCLING	CONTINUOUS
ANTIMONY	< .497-06	< .423-06
ARSENIC	< .662-06	< .564-06
BARIUM	< .132-06	< .127-06
BERYLLIUM	< .166-07	< .141-07
BISMUTH	< .828-06	< .845-06
BORON	.199-04	< .564-05
CADMIUM	< .166-05	.282-05
CHROMIUM	.414-06	.141-05
COBALT	< .828-05	< .845-05
COPPER	< .828-05	< .705-05
IRON	< .662-05	< .705-05
LEAD	< .331-04	< .282-04
MANGANESE	< .331-05	< .423-05
MERCURY	< .166-05	.634-05
MOLYBDENUM	< .116-05	< .113-05
NICKEL	< .828-05	.986-05
SELENIUM	< .497-06	< .423-06
TELLURIUM	< .993-06	< .845-06
THALLIUM	< .662-04	< .564-04
TIN	< .497-06	.845-06
TITANIUM	< .993-06	< .845-06
URANIUM	* .000	* .000
VANADIUM	< .993-06	< .986-06
ZINC	< .331-05	< .282-05
ZIRCONIUM	* .000	* .000

RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT ANALYSIS - (MCG/JOULE) -UNIT OUTLET
1ST IMPINGER

TRACE ELEMENT	TEST CONDITION			
	CYCLING		CONTINUOUS	
ANTIMONY	<	.134-06	<	.103-06
ARSENIC	<	.299-06	<	.256-06
BARIUM		.196-06	<	.249-07
BERYLLIUM	<	.446-08	<	.355-08
BISMUTH	<	.299-06	<	.256-06
BORON	*	.000	*	.000
CADMIUM	<	.446-06	<	.391-06
CHROMIUM		.714-05		.153-03
COBALT	<	.299-05		.391-05
COPPER	<	.152-05		.256-05
IRON		.361-04		.711-03
LEAD	<	.892-05	<	.640-05
MANGANESE	<	.758-06		.153-04
MERCURY		.419-05	<	.889-06
MOLYBDENUM		.491-05		.192-04
NICKEL		.937-05		.114-03
SELENIUM		.299-05		.391-05
TELLURIUM	<	.299-06	<	.256-06
THALLIUM	<	.152-04	<	.128-04
TIN		.134-05	<	.498-06
TITANIUM	<	.299-06	<	.256-06
URANIUM	*	.000	*	.000
VANADIUM	<	.152-06	<	.128-06
ZINC		.228-05		.320-05
ZIRCONIUM	*	.000	*	.000

RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT ANALYSIS - (MCG/JOULE) -UNIT OUTLET
2ND - 3RD IMPINGER

TRACE ELEMENT	TEST CONDITION			
	CYCLING		CONTINUOUS	
ANTIMONY		.767-07	<	.229-07
ARSENIC		.128-06	<	.459-07
BARIUM	*	.000	*	.000
BERYLLIUM	*	.000	*	.000
BISMUTH	*	.000	*	.000
BORON	*	.000	*	.000
CADMIUM	*	.000	*	.000
CHROMIUM	*	.000	*	.000
COBALT	*	.000	*	.000
COPPER	*	.000	*	.000
IRON	*	.000	*	.000
LEAD	*	.000	*	.000
MANGANESE	*	.000	*	.000
MERCURY	<	.512-07		.459-07
MOLYBDENUM	*	.000	*	.000
NICKEL	*	.000	*	.000
SELENIUM	*	.000	*	.000
TELLURIUM	*	.000	*	.000
THALLIUM	*	.000	*	.000
TIN	*	.000	*	.000
TITANIUM	*	.000	*	.000
URANIUM	*	.000	*	.000
VANADIUM	*	.000	*	.000
ZINC	*	.000	*	.000
ZIRCONIUM	*	.000	*	.000

APPENDIX C-3

TRACE ELEMENT FLOWRATES

(micrograms per dry standard cubic meter)

RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT ANALYSIS - (MCG/DSCM) -UNIT OUTLET
FILTER DUST

TRACE ELEMENT	TEST CONDITION	
	CYCLING	CONTINUOUS
ANTIMONY	< .471	< .344
ARSENIC	* .000	* .000
BARIUM	49.3	37.0
BERYLLIUM	< .148-01	< .107-01
BISMUTH	< .147	< .107
BORON	* .000	* .000
CADMIUM	< .148-01	< .107-01
CHROMIUM	7.59	9.05
COBALT	< .147	.358
COPPER	29.2	41.9
IRON	108.	129.
LEAD	.887	11.1
MANGANESE	2.26	5.20
MERCURY	* .000	* .000
MOLYBDENUM	2.03	1.87
NICKEL	8.23	6.24
SELENIUM	.161-01	< .134-02
TELLURIUM	< .412	< .276
THALLIUM	< .148-01	< .107-01
TIN	< .449-02	< .446-02
TITANIUM	< 1.47	8.36
URANIUM	* .000	* .000
VANADIUM	< 2.41	< .176
ZINC	< .147	< .107
ZIRCONIUM	* .000	* .000

RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT ANALYSIS - (MCG/DSCM) -UNIT OUTLET
XAD-2 CARTRIDGE

TRACE ELEMENT	TEST CONDITION	
	CYCLING	CONTINUOUS
ANTIMONY	< 1.12	< .999
ARSENIC	< 1.50	< 1.33
BARIUM	< .300	< .300
BERYLLIUM	< .375-01	< .333-01
BISMUTH	< 1.87	< 2.00
BORON	45.0	< 13.3
CADMIUM	< 3.75	6.66
CHROMIUM	.937	3.33
COBALT	< 18.7	< 20.0
COPPER	< 18.7	< 16.6
IRON	< 15.0	< 16.6
LEAD	< 75.0	< 66.6
MANGANESE	< 7.50	< 9.99
MERCURY	< 3.75	15.0
MOLYBDENUM	< 2.62	< 2.66
NICKEL	< 18.7	23.3
SELENIUM	< 1.12	< .999
TELLURIUM	< 2.25	< 2.00
THALLIUM	< 150.	< 133.
TIN	< 1.12	2.00
TITANIUM	< 2.25	< 2.00
URANIUM	* .000	* .000
VANADIUM	< 2.25	< 2.33
ZINC	< 7.50	< 6.66
ZIRCONIUM	* .000	* .000

RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT ANALYSIS - (MCG/DSCM) -UNIT OUTLET
1ST IMPINGER

TRACE ELEMENT	TEST CONDITION	
	CYCLING	CONTINUOUS
ANTIMONY	< .303	< .243
ARSENIC	< .677	< .605
BARIUM	.445	< .588-01
BERYLLIUM	< .101-01	< .840-02
BISMUTH	< .677	< .605
BORON	* .000	* .000
CADMIUM	< 1.01	< .924
CHROMIUM	16.2	361.
COBALT	< 6.77	9.24
COPPER	< 3.44	6.05
IRON	81.8	.168+04
LEAD	< 20.2	< 15.1
MANGANESE	< 1.72	36.1
MERCURY	9.50	< 2.10
MOLYBDENUM	11.1	45.3
NICKEL	21.2	269.
SELENIUM	6.77	9.24
TELLURIUM	< .677	< .605
THALLIUM	< 34.4	< 30.2
TIN	3.03	< 1.18
TITANIUM	< .677	< .605
URANIUM	* .000	* .000
VANADIUM	< .344	< .302
ZINC	5.15	7.56
ZIRCONIUM	* .000	* .000

RESIDENTIAL HEATING SYSTEM
TRACE ELEMENT ANALYSIS - (MCG/DSCM) -UNIT OUTLET
2ND - 3RD IMPINGER

TRACE ELEMENT	TEST CONDITION			
	CYCLING		CONTINUOUS	
ANTIMONY		.174	<	.542-01
ARSENIC		.290	<	.108
BARIUM	*	.000	*	.000
BERYLLIUM	*	.000	*	.000
BISMUTH	*	.000	*	.000
BORON	*	.000	*	.000
CADMIUM	*	.000	*	.000
CHROMIUM	*	.000	*	.000
COBALT	*	.000	*	.000
COPPER	*	.000	*	.000
IRON	*	.000	*	.000
LEAD	*	.000	*	.000
MANGANESE	*	.000	*	.000
MERCURY	<	.116		.108
MOLYBDENUM	*	.000	*	.000
NICKEL	*	.000	*	.000
SELENIUM	*	.000	*	.000
TELLURIUM	*	.000	*	.000
THALLIUM	*	.000	*	.000
TIN	*	.000	*	.000
TITANIUM	*	.000	*	.000
URANIUM	*	.000	*	.000
VANADIUM	*	.000	*	.000
ZINC	*	.000	*	.000
ZIRCONIUM	*	.000	*	.000

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